



TITLE:

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CITATION:

Hirose, Susumu. MAPPING CLASS GROUPS OF 3-DIMENSIONAL HANDLEBODIES AND MERIDIAN DISKS (Hyperbolic Spaces and Related Topics). 数理解析研究所講究録 1999, 1104: 1-13

ISSUE DATE:

1999-07

URL:

<http://hdl.handle.net/2433/63225>

RIGHT:

MAPPING CLASS GROUPS OF 3-DIMENSIONAL HANDLEBODIES AND MERIDIAN DISKS

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1. INTRODUCTION

A genus g *handlebody*, H_g , is an oriented 3-manifold, which is constructed from a 3-ball with attaching g 1-handles. Let $\text{Diff}^+(H_g)$ (resp. $\text{Diff}^+(\partial H_g)$) be the group of orientation preserving diffeomorphisms on H_g (resp. ∂H_g), \mathcal{H}_g (resp. \mathcal{M}_g) be a group which consists of isotopy classes of $\text{Diff}^+(H_g)$ (resp. $\text{Diff}^+(\partial H_g)$). Generators of \mathcal{H}_g are given in [11] and [7]. Wajnryb gave a presentation for \mathcal{H}_g in [12]. In this note, we give a presentation for \mathcal{H}_g with using other method. When $g \geq 3$, we use a simplicial action of \mathcal{H}_g on simplicial complex (which is a subcomplex of a contractible complex defined by McCullough [10]) defined as follows: its vertices are isotopy classes of *meridian disks* in H_g (essential 2-disks properly embedded in H_g), and its simplex is a system of isotopy classes of meridian disks which are represented by disks, which are disjoint and non-isotopic each other and whose complements is connected. This complex is $(g - 2)$ -connected, especially, if $g \geq 3$, it is simply connected. (When $g = 2$, unfortunately, this complex is not simply connected, hence we use a contractible complex defined in [10].) This is subcomplex of a complex X defined by Harer in [5]. Since the orbit space of the former one by \mathcal{H}_g is identical with the latter one by \mathcal{M}_g , our method can be applied to giving a presentation for \mathcal{M}_g without using a complex defined by Hatcher and Thurston [4].

This note is a summary of a paper [6].

1991 *Mathematics Subject Classification*. 57N05, 57N10.

Key words and phrases. 3-dimensional handlebody, mapping class group.

This research was partially supported by Grant-in-Aid for Encouragement of Young Scientists (No. 10740035), Minsitry of Education, Science, Sports and Culture, Japan

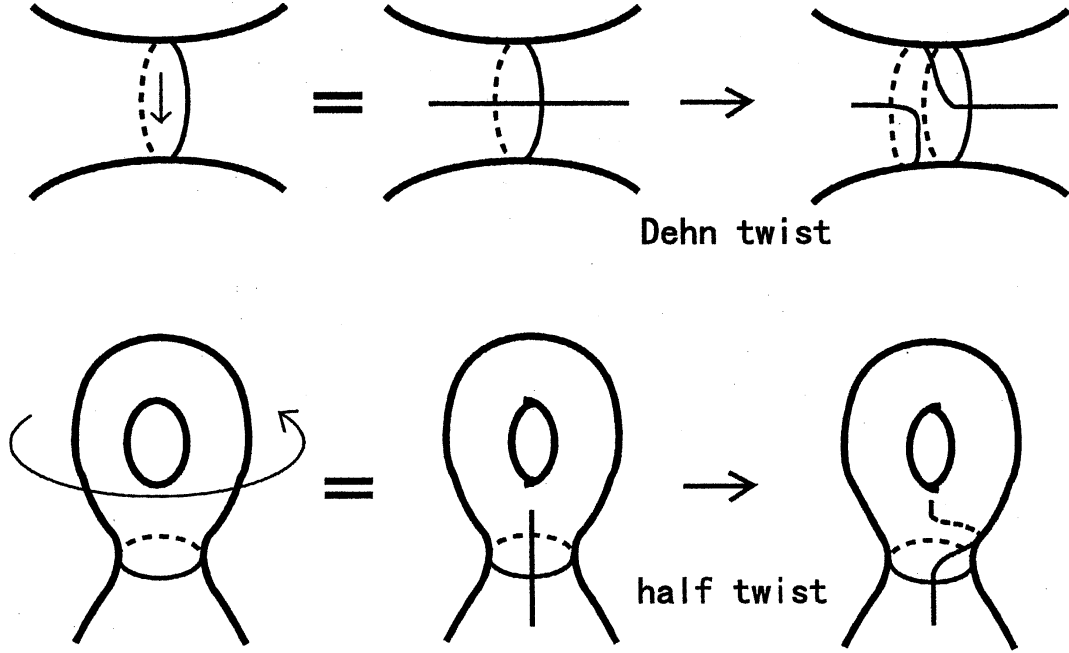


FIGURE 1

2. A PRESENTATION FOR \mathcal{H}_g

Before we state a presentation for \mathcal{H}_g , we set notations used there. Sometimes, we indicate an element of \mathcal{H}_g by a figure. In Figure 1, the left hand side figure denotes an element given in the right hand side figure. The symbol \rightleftharpoons means *commute with*. For example, if L, M, N are any elements of \mathcal{H}_g , a relation $L \rightleftharpoons M, N$ means that $LM = ML$, $LN = NL$. The commutator of A and B , $A^{-1}B^{-1}AB$, is denoted by $[A, B]$. In this paper, we consider that the group \mathcal{H}_g acts on H_g from the right: for any elements ϕ_1, ϕ_2 of \mathcal{H}_g , $\phi_1\phi_2$ means apply ϕ_1 first, then apply ϕ_2 .

Theorem 2.1. *Let a_1, k_1, d_i ($2 \leq i \leq g$), $t(2)_{21}, r(2)_{21}$ be the elements of \mathcal{H}_g indicated in Figure 2. The group \mathcal{H}_g admits a presentation with generators a_1, k_1, d_i ($2 \leq i \leq g$), $t(2)_{21}, r(2)_{21}$ and defining relations:*
if $g \geq 4$,

$$\begin{aligned}
 (A1) \quad & d_m^{-1} a_m d_m = a_{m-1}, \quad d_m^{-1} a_{m-1} d_m = a_m, \\
 & d_m^{-1} k_m d_m = k_{m-1}, \quad d_m^{-1} k_{m-1} d_m = k_m, \\
 & \text{where } 2 \leq m \leq g,
 \end{aligned}$$

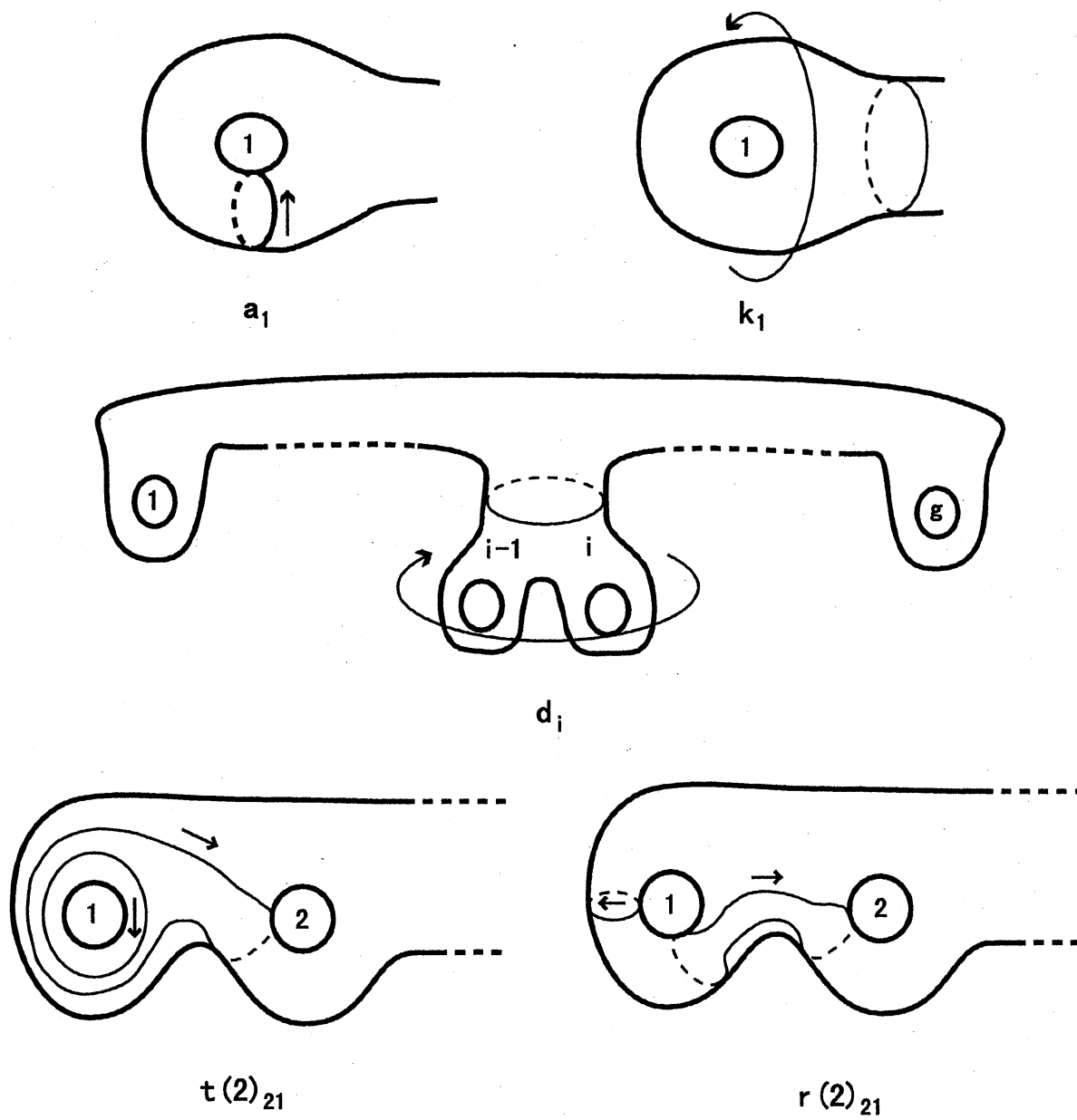


FIGURE 2

$$(A2) \quad r_g = \begin{cases} d_2 d_3 \cdots d_g k_1^{-1} k_2^{-1} \cdots k_{g-1}^{-1}, & g \text{ is odd,} \\ d_2 d_3 \cdots d_g k_1^{-1} k_2^{-1} \cdots k_g^{-1}, & g \text{ is even,} \end{cases}$$

$$(A3) \quad d_1 = r_g^{-1} d_2 r_g,$$

$$(A4) \quad r(m)_{1j} = k_m r(m)_{2j} k_m^{-1}, \quad t(m)_{1j} = k_m t(m)_{2j} k_m^{-1},$$

$$(A5) \quad \begin{aligned} r(m)_{ij} &= d_j k_{j-1}^{-1} r(m)_{i,j-1} k_{j-1} d_j^{-1}, \\ t(m)_{ij} &= d_j k_{j-1}^{-1} t(m)_{i,j-1} k_{j-1} d_j^{-1}, \end{aligned}$$

where $m = 1, \dots, g$, $i = 1, 2$, $j \neq m, m-1$, and index j is given modulo g ,

$$(A6) \quad \begin{aligned} r(m)_{ij} &= d_m k_{m-1}^{-1} r(m-1)_{i,j} k_{m-1} d_m^{-1}, \\ t(m)_{ij} &= d_m k_{m-1}^{-1} t(m-1)_{i,j} k_{m-1} d_m^{-1}, \end{aligned}$$

where $m = 1, \dots, g$, $i = 1, 2$, $j \neq m, m-1$, and index j is given modulo g ,

$$(A7) \quad c(m)_i[j, j+1, \dots, j+k] = \left(\prod_{n=0}^k [t(m)_{i,j+n}, r(m)_{i,j+n}^{-1}] \right) a_m^{-(2k+1)},$$

where $i = 1, 2$, and index j is given modulo g ,

$$(A8) \quad A_m = k_m^{-2}, \text{ where } 1 \leq m \leq g,$$

$$(A9) \quad t_1 = t(2)_{21} k_1^{-1} a_2,$$

$$(B1) \quad \begin{aligned} d_i &\rightleftharpoons d_j, \text{ where } |i-j| \geq 2, \\ d_i^{-1} d_{i-1}^{-1} d_i d_{i-1} d_i &= d_{i-1} \text{ where } 2 \leq i \leq g, \end{aligned}$$

$$(B2) \quad \begin{aligned} k_1 &\rightleftharpoons k_2, \\ a_1 &\rightleftharpoons a_2, \end{aligned}$$

$$(B3) \quad \begin{aligned} a_1, k_1 &\rightleftharpoons d_i, \text{ where } 3 \leq i \leq g, \\ a_g, k_g &\rightleftharpoons d_j, \text{ where } 2 \leq j \leq g-1, \end{aligned}$$

$$(B4) \quad k_1 \rightleftharpoons a_1, a_2,$$

$$(B5) \quad d_3 \rightleftharpoons a_1,$$

$$(B6) \quad t(3)_{11}, r(3)_{11} \rightleftharpoons t(3)_{22}, r(3)_{22},$$

$$(B7) \quad \begin{aligned} t(2)_{21} A_2 t(2)_{11} A_2^{-1} t(2)_{21}^{-1} &= t(2)_{11}, \\ t(2)_{21} A_2 r(2)_{11} A_2^{-1} t(2)_{21}^{-1} &= a_2^{-2} A_2 r(2)_{11} \\ r(2)_{21} A_2 t(2)_{11} r(2)_{21}^{-1} &= a^{-2} t(2)_{11} \\ r(2)_{21} A_2 r(2)_{11} A_2^{-1} r(2)_{21}^{-1} &= r(2)_{11} \end{aligned}$$

$$(B8) \quad \begin{aligned} k_1^{-1} t(2)_{21} k_1 &= t(2)_{21}^{-1} r(2)_{21} t(2)_{21}^{-1} r(2)_{21}^{-1} t(2)_{21}, \\ k_1^{-1} r(2)_{21} k_1 &= t(2)_{21}^{-1} r(2)_{21}^{-1} t(2)_{21}, \end{aligned}$$

$$(B9) \quad \begin{aligned} a_1 &\rightleftharpoons r(2)_{21}, \\ a_1^{-1} t(2)_{21} a_1 &= (r(2)_{21})^{-1} t(2)_{21} \end{aligned}$$

$$(B10) \quad a_2 \rightleftharpoons t(2)_{21}, r(2)_{21},$$

$$(B11) \quad d_2 \rightleftharpoons r(2)_{21} (a_1)^{-1}$$

$$(B12) \quad a_3, k_3 \rightleftharpoons t(2)_{21}, r(2)_{21},$$

$$(B13) \quad t(2)_{2,1}, r(2)_{2,1} \rightleftharpoons t(4)_{2,3}, r(4)_{2,3},$$

$$(B14) \quad \begin{aligned} t(2)_{2,1}^{-1} t(3)_{2,1} t(2)_{2,1} &= (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2})^{-1} t(3)_{2,1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}), \\ t(2)_{2,1}^{-1} t(3)_{2,1}^{-1} r(3)_{2,1} t(2)_{2,1} &= a_3^{-1} t(3)_{2,1}^{-1} r(3)_{2,1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}), \\ t(2)_{2,1}^{-1} t(3)_{2,2} t(2)_{2,1} &= a_3^{-1} t(3)_{2,2} t(3)_{2,1}^{-1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}), \\ t(2)_{2,1} &\rightleftharpoons r(3)_{2,2}, \end{aligned}$$

$$(B15) \quad \begin{aligned} r(2)_{2,1}^{-1} t(3)_{2,1} r(2)_{2,1} &= a_3^{-1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2})^{-1} t(3)_{2,1}, \\ r(2)_{2,1}^{-1} r(3)_{2,1} r(2)_{2,1} &= (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2})^{-1} r(3)_{2,1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}), \\ r(2)_{2,1}^{-1} t(3)_{2,2} r(2)_{2,1} &= a_3^{-1} t(3)_{2,2} r(3)_{2,1}^{-1} (t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}), \\ r(2)_{2,1} &\rightleftharpoons r(3)_{2,2}, \end{aligned}$$

$$(B16) \quad d_2^2 = a_2^{-4} \{ (t(2)_{11})^{-1} r(2)_{11} t(2)_{11} (r(2)_{11})^{-1} \} k_2^2 \{ (t(2)_{21})^{-1} r(2)_{21} t(2)_{21} (r(2)_{21})^{-1} \} k_1^2,$$

$$\begin{aligned}
(B17) \quad & r(g)_{2,g-1}, t(g)_{2,g-1} \rightleftharpoons d_i \text{ where } 2 \leq i \leq g-2, \\
& r(g)_{2,1}, t(g)_{2,1} \rightleftharpoons d_i \text{ where } 3 \leq i \leq g-1, \\
& t(2)_{2,1}, t(2)_{2,1} \rightleftharpoons d_i \text{ where } 4 \leq i \leq g,
\end{aligned}$$

$$\begin{aligned}
(B18) \quad & d_2^{-1} r(3)_{2,1} d_1 \\
& = t(3)_{2,1}^{-1} r(3)_{2,1} t(3)_{2,1} r(3)_{2,1}^{-1} \times t(3)_{2,2}^{-1} r(3)_{2,2}^{-1} t(3)_{2,2} \\
& \quad \times r(3)_{2,1} t(3)_{2,1}^{-1} r(3)_{2,1}^{-1} t(3)_{2,1}, \\
& d_2^{-1} t(3)_{2,1} d_2 \\
& = t(3)_{2,1}^{-1} r(3)_{2,1} t(3)_{2,1} r(3)_{2,1}^{-1} \times t(3)_{2,2}^{-1} r(3)_{2,2} t(3)_{2,2}^{-1} r(3)_{2,2}^{-1} t(3)_{2,2} \\
& \quad \times r(3)_{2,1} t(3)_{2,1}^{-1} r(3)_{2,1}^{-1} t(3)_{2,1},
\end{aligned}$$

$$(B19) \quad (d_2^{-1} t_1 d_2 t_1)^3 = d_2^2,$$

$$(B20) \quad A_g = \prod_{i=1}^{g-1} [t(g)_{2,i}, r(g)_{2,i}^{-1}] a_g^{-2(g-1)},$$

$$(B21) \quad r(2)_{11} = r(1)_{12} a_1 a_2^{-1}$$

$$(B22) \quad t(2)_{11} t(2)_{21} A_2 a_2^2 = \prod_{i=3}^g \{t(i)_{2,1}^{-1} t(i)_{1,1}^{-1} c(i)_2 [2, \dots, i-1] c(i)_1 [2, \dots, i-1] A_i^{-1} a_i^{-4}\},$$

$$(B23) \quad k_1^2 A_2 = \prod_{i=3}^g \{c(i)_2 [2, \dots, i-1] c(i)_1 [2, \dots, i-1] A_i^{-1} a_i^{-2}\},$$

and if $g = 3$, the above relations except (B13) and (B17) are satisfied and sufficient, and if $g = 2$, (A1), (A4), (A8), (A9), (B2), (B4), (B7), (B8), (B9), (B10), (B11), (B20) and

$$(B16') \quad d_2^2 = 1,$$

$$(B19') \quad (d_2^{-1} t_1 d_2 t_1)^3 = 1,$$

$$(B21') \quad r(2)_{11} r(2)_{21} A_2 a_2^2 = 1,$$

$$(B22') \quad t(2)_{11} t(2)_{21} A_2 a_2^2 = 1,$$

$$(B23') \quad k_1^2 A_2 = 1,$$

are satisfied and sufficient.

In this presentation, (A^*) 's are the relations which define some generators from a_1, k_1, d_i ($2 \leq i \leq g$), $t(2)_{2,1}$, and $r(2)_{2,1}$ (these are indicated in the sequel of this paper by Figures). (B^*) 's are easily checked by drawing some figures. From here to the end of this paper, we will show sufficiency of these relations.

3. DISK COMPLICES

Let H_g be a three dimensional handlebody of genus g , E_1, \dots, E_l be mutually disjoint 2-disks embedded in ∂H_g . By a *disc* in $(H_g, \{E_1, \dots, E_l\})$ we mean a properly imbedded 2-disc $(D, \partial D) \subseteq (H_g, \partial H_g)$ which is disjoint from $E_1 \cup \dots \cup E_l$. The disc D is called *meridian disc* in $(H_g, \{E_1, \dots, E_l\})$ when $H_g - D$ is connected. Define the *nonseparating disc complex* of H_g to be the simplicial complex $L'(H_g, \{E_1, \dots, E_l\})$ whose vertices(0-simplices) are the isotopy classes of meridian discs in $(H_g, \{E_1, \dots, E_l\})$, and whose simplices are determined by the rule that a collection of $n+1$ distinct vertices spans an n -simplex if and only if it admits a collection of representative which are pairwise disjoint. Define the complex $Y(H_g, \{E_1, \dots, E_l\})$ to be the subcomplex of $L'(H_g, \{E_1, \dots, E_l\})$ whose n -simplex is determined by $n+1$ distinct vertices represented by pairwise disjoint discs D_0, D_1, \dots, D_n such that $H_g - D_0 \cup D_1 \cup \dots \cup D_n$ is connected. If there is no distinguished discs $\{E_1, \dots, E_l\}$ on ∂H_g , we denote these complices by the notation $L'(H_g)$ and $Y(H_g)$. We call a *system of meridian discs* the set of mutually disjoint and nonisotopic meridian discs in $(H_g, \{E_1, \dots, E_l\})$. Each simplex of $L'(H_g, \{E_1, \dots, E_l\})$ is represented by a system of meridian disks. The definition of $L'(H_g, \{E_1, \dots, E_l\})$ is a modification of the *disc complex* defined in section 5 of [10]. The following theorem is proved by a slight modification of the proof for Theorem 5.2 of [10].

Theorem 3.1. $L'(H_g, \{E_1, \dots, E_l\})$ is contractible. \square

We will show the following theorem.

Theorem 3.2. $Y(H_g, \{E_1, \dots, E_l\})$ is $(g-2)$ -connected.

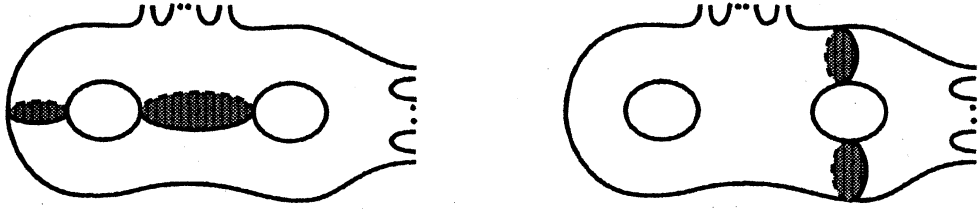


FIGURE 3

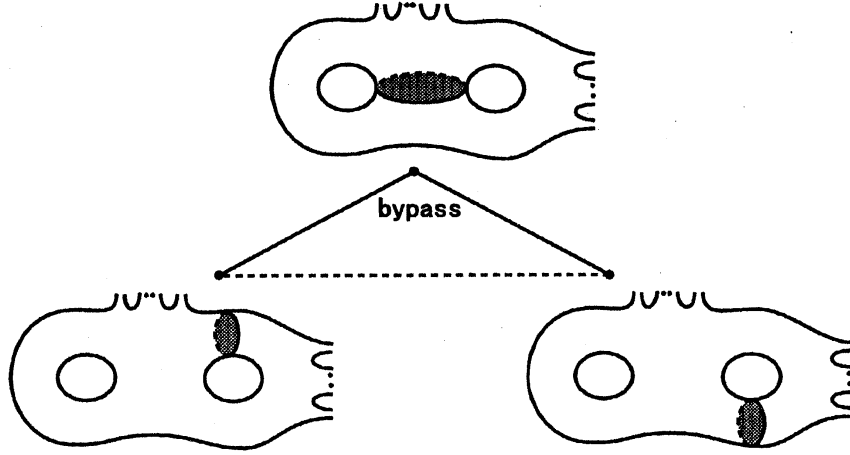


FIGURE 4

This complex $Y(H_g, \{E_1, \dots, E_l\})$ resembles complices X defined in [5] and Y defined in [3]. We prove the above theorem as in the proof of Theorem 1.1 of [5] and the proof of Proposition of [3].

Proof. We prove this theorem by the induction of genus g .

At first, we prove $Y(H_2, \{E_1, \dots, E_l\})$ is connected (0-connected). By 3.1, $L'(H_2, \{E_1, \dots, E_l\})$ is connected. As is indicated in Figure 3, there are two types of edges in $L'(H_2, \{E_1, \dots, E_l\})$. The first one is in $Y(H_2, \{E_1, \dots, E_l\})$. The second one is not in $Y(H_2, \{E_1, \dots, E_l\})$, but there is a bypass in $Y(H_2, \{E_1, \dots, E_l\})$ given in Figure 4. Hence, $Y(H_2, \{E_1, \dots, E_l\})$ is connected.

We assume, for any integer k smaller than g , $Y(H_k, \{E_1, \dots, E_l\})$ is $(k-2)$ -connected. Let i be an integer smaller than or equal to $g-2$, and $f : S^i \rightarrow Y(H_g, \{E_1, \dots, E_l\})$ be a continuous map. Since $L'(H_g, \{E_1, \dots, E_l\})$ is contractible, there is a continuous map $\tilde{f} : D^{i+1} \rightarrow L'(H_g, \{E_1, \dots, E_l\})$ such that $\tilde{f}|_{\partial D^{i+1}} = f$.

We may assume \tilde{f} is piecewise linear with respect to some triangulation of D^{i+1} . If $\tilde{f}(D^{i+1})$ is contained in $Y(H_g, \{E_1, \dots, E_l\})$, this means that f is null-homotopic. We assume $\tilde{f}(D^{i+1})$ is not contained in $Y(H_g, \{E_1, \dots, E_l\})$. Then, there is a simplex σ of D^{i+1} such that $\tilde{f}(\sigma)$ is not contained in $Y(H_g, \{E_1, \dots, E_l\})$, and this means that there is a representative $\{D_0 \cup \dots \cup D_j\}$ of $\tilde{f}(\sigma)$ with disconnected complement. Let G_σ be a graph defined as follows. Each vertex corresponds to components of $H_g - D_0 \cup \dots \cup D_j$. Each edge corresponds to one of D_0, \dots, D_j and connecting vertices corresponding to the components containing this disc. Since $D_0 \cup \dots \cup D_j$ has disconnected complement, G_σ has at least two components. There is a nonempty subgraph of G_σ whose edges connects distinct vertices. Let \mathcal{D} be the subsystem of $\{D_0, \dots, D_j\}$ which corresponds to the edges of this graph. This system \mathcal{D} satisfies the following property:

(*) Let $\mathcal{D} = \{D'_0, \dots, D'_m\}$. Each $D'_a \in \mathcal{D}$ separates $H_g - \bigcup_{n \neq a} D'_n$.

A system of meridian discs which satisfies property(*) is called *purely separating* system of meridian discs, and a simplex of $L'(H_g, \{E_1, \dots, E_l\})$ is called *purely separating* if it is represented by a purely separating system of meridian discs. \mathcal{D} represent a face of $\tilde{f}\sigma$, so there is a simplex τ of D^{i+1} such that $\tilde{f}(\tau)$ is purely separating. In general, we have shown the following lemma.

Lemma 3.3. *Each simplex in $L'(H_g, \{E_1, \dots, E_l\})$ has a face which is purely separating.*

Let σ be a simplex of D^{i+1} of maximal dimension p such that $\tilde{f}(\sigma)$ is purely separating. This simplex σ is not contained in ∂D^{i+1} , hence, *Link* σ is homeomorphic to S^{i-p} . Let $\{D_0, \dots, D_p\}$ be a system of meridian discs which represents $\tilde{f}(\sigma)$, and let $M = H_g - D_0 \cup \dots \cup D_p$. We define the complex $Y(M, *)$ for $(M, \{E_1, \dots, E_l, \text{discs which are emerged as a cut end along } D_0 \cup \dots \cup D_p\})$ in the same manner as $Y(H_g, \{E_1, \dots, E_l\})$. Then, each disc which represents each vertex of *Link* σ does not separate M . In fact, if some vertex v of *Link* σ separates M , then

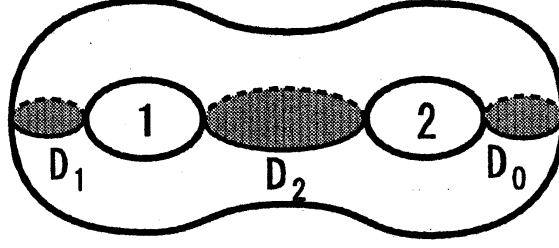


FIGURE 5

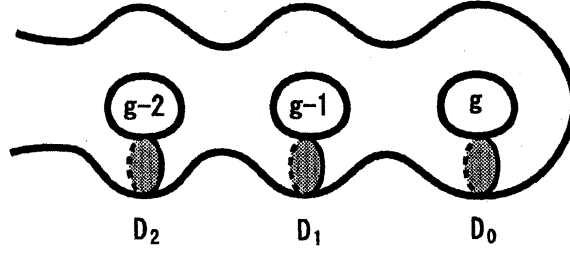


FIGURE 6

$\tilde{f}(v * \sigma)$ is purely separating, and this fact contradicts the maximality assumption of p . Hence, each vertex of $Link \sigma$ is mapped into $Y(M, *)$ by \tilde{f} . If there is a simplex ρ of $Link \sigma$ such that $\tilde{f}(\rho)$ separates M , then, by 3.3 there is a face τ of ρ such that $\tilde{f}(\tau)$ is purely separating. Then $\tilde{f}(\tau * \sigma)$ is purely separating, and $\tau * \sigma \subset Link \sigma \subset D^{i+1}$. This fact contradicts the maximality assumption of p . Hence, $\tilde{f}(Link \sigma) \subset Y(M, *)$. By the way, M is a disjoint union of handle bodies, and the total number m of these genera is at least $g - p$. $Y(M)$ is a join of Y 's of each components of M . Hence, by the hypothesis for the induction, $Y(M)$ is $(m - 2)$ -connected. Here, we remember that $i \leq g - 2$, then we can see $i - p \leq g - 2 - p \leq m - 2$. This shows that $\tilde{f}|_{Link \sigma}$ is null homotopic in $Y(M)$, hence, in $Y(H_g, \{E_1, \dots, E_l\})$. Therefore, we can homotope \tilde{f} such that $\tilde{f}(Link \sigma) \subset Y(H_g, \{E_1, \dots, E_l\})$. We do the same way for other simplices whose images are purely separating, then \tilde{f} is homotoped to a continuous map whose image is in $Y(H_g, \{E_1, \dots, E_l\})$. \square

4. OBTAINING A PRESENTATION FROM THE ACTION OF \mathcal{H}_g ON $Y(H_g)$

For each element ϕ of \mathcal{H}_g and simplex $([D_0], \dots, [D_n])$ of $Y(H_g)$ (resp. $\Delta'(H_g)$), $([\phi(D_0)], \dots, [\phi(D_n)])$ is also a simplex of $Y(H_g)$ (resp. $\Delta'(H_g)$). Hence, we

can define a right action of \mathcal{H}_g on $Y(H_g)$ (resp. $\Delta'(H_g)$) by $([D_0], \dots, [D_n])\phi = ([\phi(D_0)], \dots, [\phi(D_n)])$. We can see that, if $g = 2$, each of $\{2\text{-simplices of } \Delta'(H_2)\}/\mathcal{H}_2$, $\{1\text{-simplices of } \Delta'(H_2)\}/\mathcal{H}_2$ and $\{\text{vertices of } \Delta'(H_2)\}/\mathcal{H}_2$ consists of one element, each of which is represented by $([D_0], [D_1], [D_2])$, $([D_0], [D_1])$, and $([D_0])$, where D_0, D_1, D_2 are indicated in Figure 5, and if $g \geq 3$, each of $\{2\text{-simplices of } Y(H_g)\}/\mathcal{H}_g$, $\{1\text{-simplices of } Y(H_g)\}/\mathcal{H}_g$ and $\{\text{vertices of } Y(H_g)\}/\mathcal{H}_g$ consists of one element, each of which is represented by $([D_0], [D_1], [D_2])$, $([D_0], [D_1])$, and $([D_0])$, where D_0, D_1, D_2 are indicated in Figure 6. If stabilizer of each vertex is finitely presented, and if that of each 1-simplex is finitely generated, we can obtain a presentation for \mathcal{H}_g as in the way of [9], [12]. Here, we will mention these method. The action of \mathcal{H}_2 on $\Delta'(H_2)$ is similar to the action of \mathcal{H}_g on 2-skelton of $Y(H_g)$ when $g \geq 3$. Hence, we mention just on the case of $g \geq 3$.

We fix a vertex v_0 of $Y(H_g)$, fix an edge (= a 1-simplex with orientation) e_0 of $Y(H_g)$ which emanates from v_0 and fix a 2-simplex f_0 of $Y(H_g)$ which contains v_0 . Let D_0, D_1 and D_2 be meridian disks indicated in Figure 6, we set $v_0 = [D_0]$, $e_0 = ([D_0], [D_1])$ and $f_0 = ([D_0], [D_1], [D_2])$. We choose an element r_0 of \mathcal{H}_g which switches the vertices of e_0 , in our situation, we set $r_0 = d_g$. By this notation, we see $e_0 = (v_0, (v_0)d_g)$. We denote the stabilizer of v_0 by $(\mathcal{H}_g)_{v_0}$, that of e_0 by $(\mathcal{H}_g)_{e_0}$ and an infinite cyclic group generated by d_g by $\langle d_g \rangle$. The free product $(\mathcal{H}_g)_{v_0} * \langle d_g \rangle$ with the following three types of relation define a presentation for \mathcal{H}_g .

(Y1) $d_g^2 = \text{a presentation of } d_g^2 \text{ as an element of } (\mathcal{H}_g)_{v_0}$.

(Y2) For each element t of $(\mathcal{H}_g)_{e_1}$,

$$\begin{aligned} & (d_g)^{-1}(\text{ a presentation of } t \text{ as an element of } (\mathcal{H}_g)_{v_0})d_g \\ & = \text{ a presentation of } (d_g)^{-1}td_g \text{ as an element of } (\mathcal{H}_g)_{v_0}. \end{aligned}$$

(Y3) For the loop ∂f_0 in $Y(H_g)$, we define an element W_{f_0} in the following manner. The loop ∂f_0 consists of three vertices v_0, v_1, v_2 and three edges e_1, e_2, e_3 such that $e_1 = (v_0, v_1)$, $e_2 = (v_1, v_2)$, $e_3 = (v_2, v_0)$. There is an element h_1 of $(\mathcal{H}_g)_{v_0}$ such that $e_0 h_1 = e_1$ i.e. $e_1 = (v_0, (v_0)d_g h_1)$, then $e_2(d_g h_1)^{-1}$ is an edge emanat-

ing from v_0 . Hence, there is an element h_2 of $(\mathcal{H}_g)_{v_0}$ such that $e_0 h_2 = e_2 (d_g h_1)^{-1}$ i.e. $e_2 = ((v_0) d_g h_1, (v_0) d_g h_2 d_g h_1)$, then $e_3 (d_g h_2 d_g h_1)^{-1}$ is an edge emanating from v_0 . So, there is an element h_3 of $(\mathcal{H}_g)_{v_0}$ such that $e_0 h_3 = e_3 (d_g h_2 d_g h_1)^{-1}$ i.e. $e_3 = ((v_0) d_g h_2 d_g h_1, (v_0) d_g h_3 d_g h_2 d_g h_1)$. We define $W_{f_0} = d_g h_3 d_g h_2 d_g h_1$. This element W_{f_0} fixes v_0 , so the following is a relation for \mathcal{H}_g . W_{f_0} is a presentation of W_{f_0} as an element of $(\mathcal{H}_g)_{v_0}$. If $g \geq 3$, then this type of relation is $d_g d_{g-1} d_g = d_{g-1} d_g d_{g-1}$, and if $g = 2$, then this type of relation is $(d_2^{-1} t_1 d_2 t_1)^3 = 1$, where $t_1 = t(2)_{2,1} k_1^{-1} a_2$.

For subsets A_1, \dots, A_n of H_g , we define $Diff^+(H_g, A_1, \dots, A_n) = \{\phi \in Diff^+(H_g) \mid \phi(A_1) = A_1, \dots, \phi(A_n) = A_n\}$. We can see $(\mathcal{H}_g)_{v_0} = \pi_0(Diff^+(H_g, D_0))$, and $(\mathcal{H}_g)_{e_0} = \pi_0(Diff^+(H_g, D_0, D_1))$. Let $\Sigma_g = \partial H_g$ and let $F_n \Sigma_g$ be the space of all ordered n -tuples of distinct points of Σ_g : $F_n \Sigma_g = \{(p_1, \dots, p_n) \mid \text{each } p_i \in \Sigma_g, \text{ and } p_i \neq p_j \text{ if } i \neq j\}$. We define the n -string pure braid group $P_n(\Sigma_g)$ to be the fundamental group of $F_n \Sigma_g$. Let p_1 and p_2 be points on ∂H_{g-1} , and $p_{0,1}, p_{0,2}, p_{1,1}$, and $p_{1,2}$ be points on ∂H_{g-2} .

We can get a presentation for $(\mathcal{H}_g)_{v_0}$ by investigating the following three exact sequences:

$$\begin{aligned} (1) \quad & P_2 \Sigma_{g-1} \xrightarrow{\beta} \pi_0(Diff^+(H_{g-1}, p_1, p_2)) \xrightarrow{\alpha\#} \mathcal{H}_{g-1} (= \pi_0(Diff^+(H_{g-1}))) \longrightarrow 0, \\ (2) \quad & 0 \longrightarrow \pi_0(Diff^+(H_{g-1}, p_1, p_2)) \xrightarrow{\delta} \pi_0(Diff^+(H_{g-1}, \{p_1, p_2\})) \xrightarrow{\gamma} \mathbb{Z}_2 \longrightarrow 0, \\ (3) \quad & 0 \longrightarrow \mathbb{Z} \longrightarrow \pi_0(Diff^+(H_g, D_0)) \xrightarrow{\lambda} \pi_0(Diff^+(H_{g-1}, \{p_1, p_2\})) \longrightarrow 0. \end{aligned}$$

We can get a set of generators of $(\mathcal{H}_g)_{e_0}$ by investigating the following three exact sequences:

$$\begin{aligned} (4) \quad & P_4 \Sigma_{g-2} \xrightarrow{\beta} \pi_0(Diff^+(H_{g-2}, p_{0,1}, p_{0,2}, p_{1,1}, p_{1,2})) \xrightarrow{\alpha\#} \mathcal{H}_{g-2} (= \pi_0(Diff^+(H_{g-2}))) \longrightarrow 0, \\ (5) \quad & 0 \longrightarrow \pi_0(Diff^+(H_{g-2}, p_{0,1}, p_{0,2}, p_{1,1}, p_{1,2})) \xrightarrow{\delta} \\ & \pi_0(Diff^+(H_{g-2}, \{p_{0,1}, p_{0,2}\}, \{p_{1,1}, p_{1,2}\})) \xrightarrow{\gamma} \mathbb{Z}_2 \times \mathbb{Z}_2 \longrightarrow 0 \end{aligned}$$

$$(6) \quad 0 \longrightarrow \mathbb{Z} \times \mathbb{Z} \longrightarrow \pi_0(Diff^+(H_g, D_0, D_1)) \\ \xrightarrow{\lambda} \pi_0(Diff^+(H_{g-2}, \{p_{0,1}, p_{0,2}\}, \{p_{1,1}, p_{1,2}\})) \longrightarrow 0.$$

We can give relations of type (Y1) and (Y2) by drawing some figures.

For details please see [6].

ACKNOWLEDGEMENTS

The author would like to express his gratitude to Prof. D. McCullough and Prof. B. Wajnryb for sending their papers to him.

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